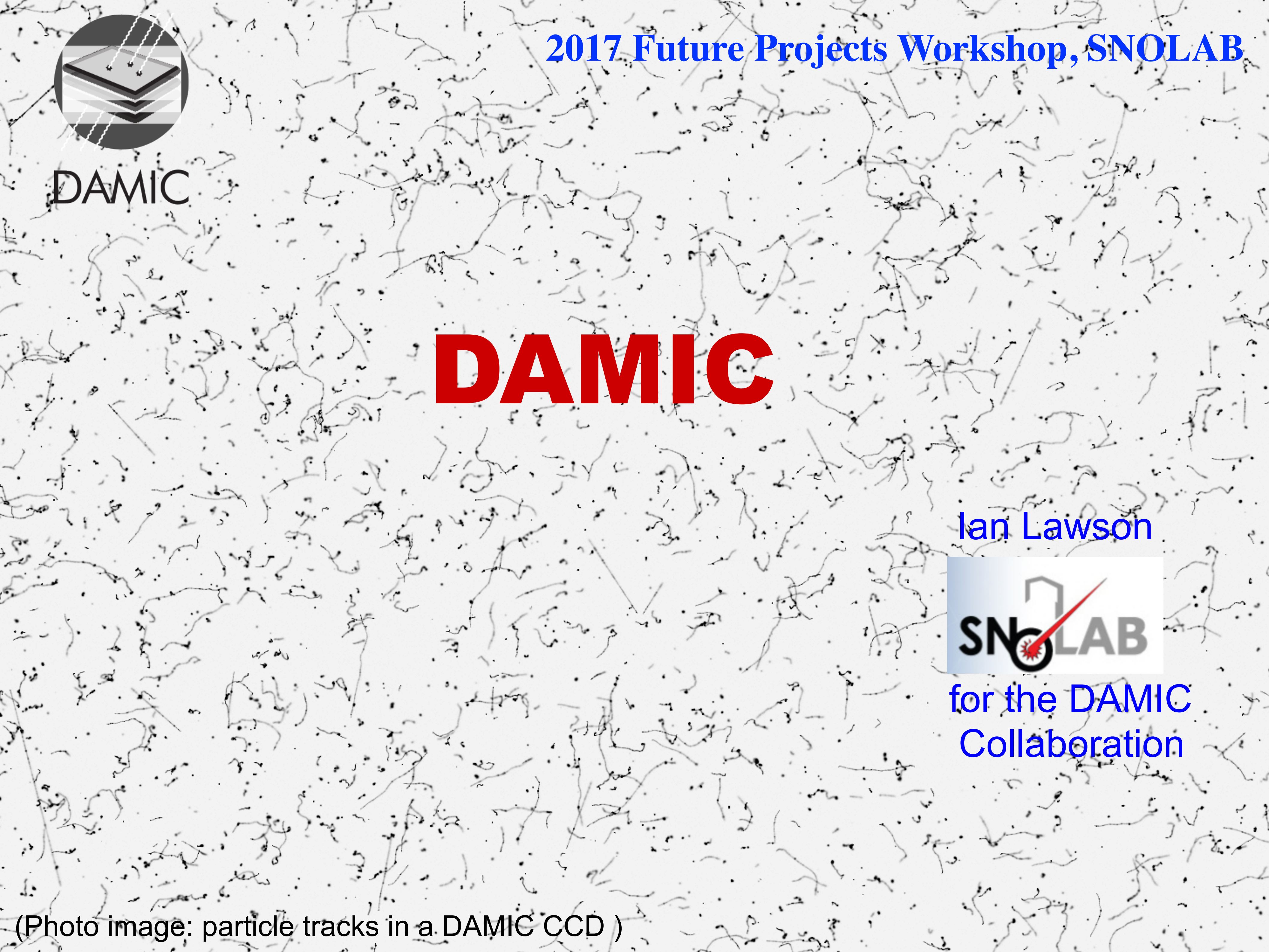
DAMIC

Ian Lawson

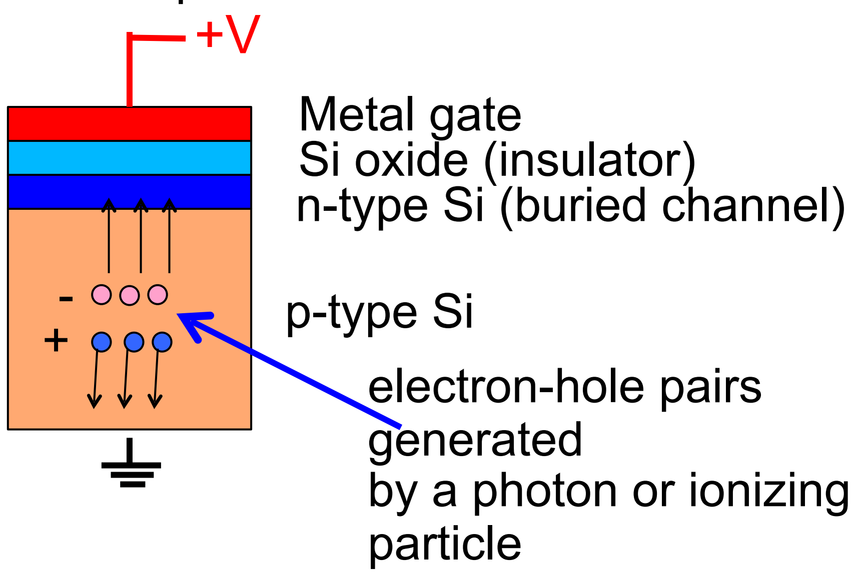
for the DAMIC Collaboration



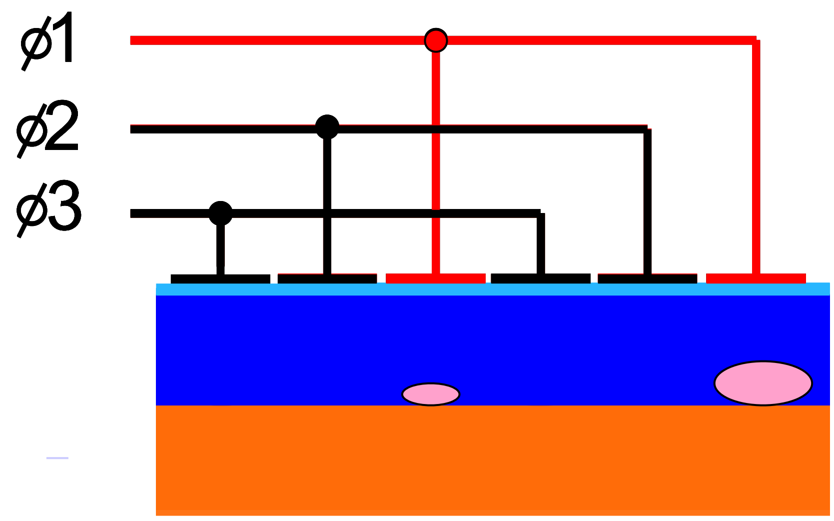
(Photo image: particle tracks in a DAMIC CCD)

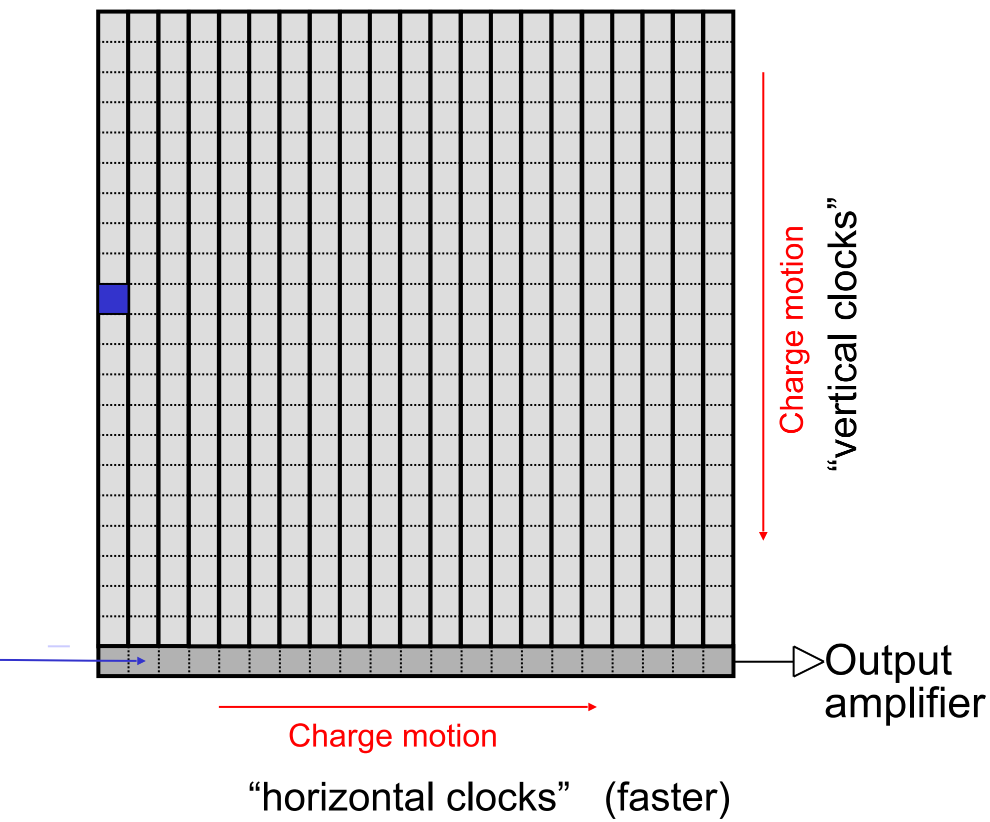
CCD principle

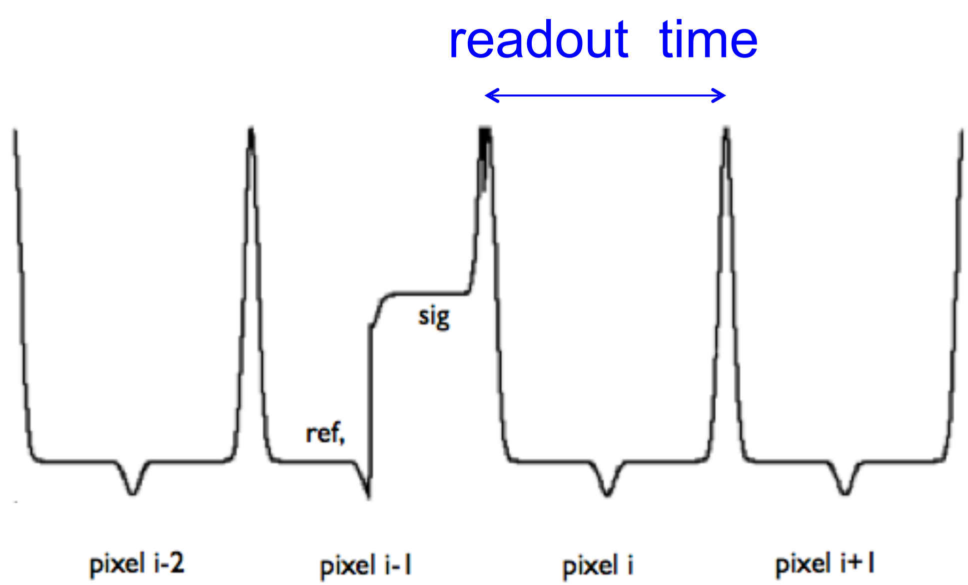
Metal-Oxide-Semiconductor capacitor



Moving charge from pixel to pixel

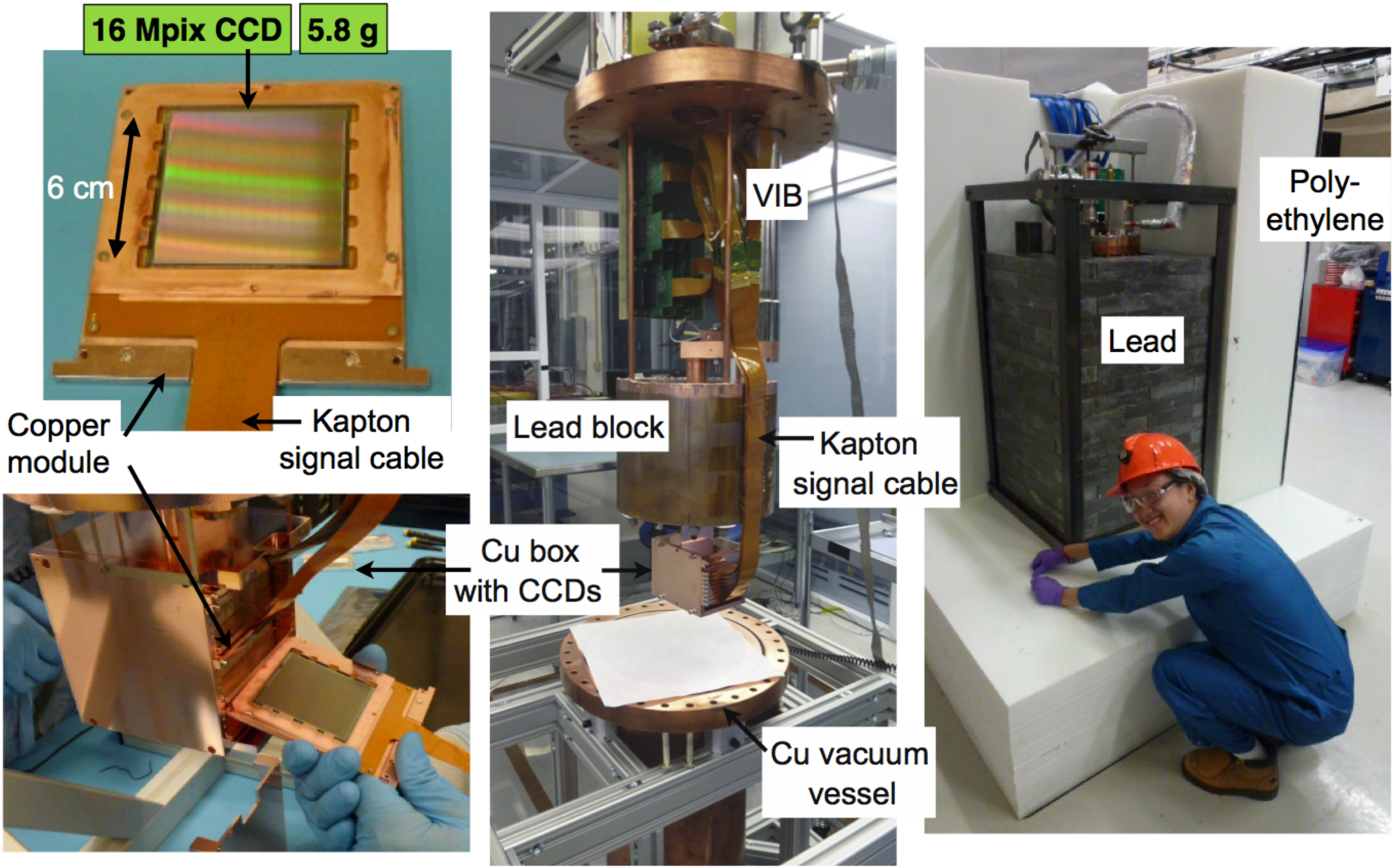






Correlated Double Sampling

DAMIC @ SNOLAB



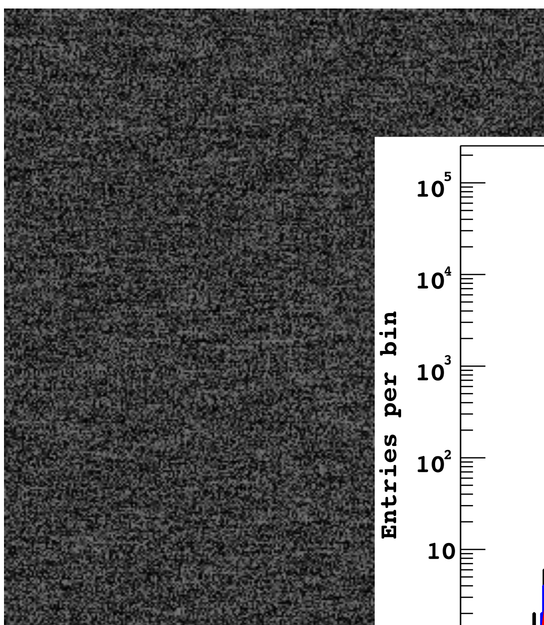
1) Sizable mass (high resistivity, thick CCDs designed by LBNL)

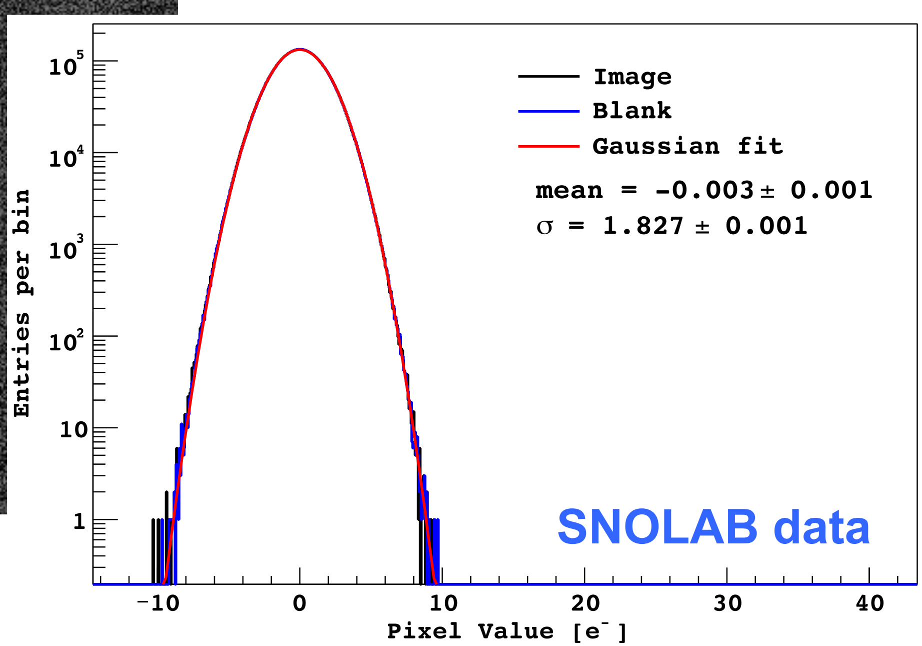
A DAMIC CCD has an active area of 6 cm x 6 cm, 16 Mpixel (each 15 μm x 15 μm) and a record thickness of 675 μm for a total of 5.9 g mass

DAMIC100 currently taking data at the SNOLAB underground laboratory

2) Unprecedented low energy threshold

- Negligible noise contribution from dark current fluctuations (dark current < 0.001 e-/pixel/day with CCD cooled at 120 K). Readout noise dominant contribution.





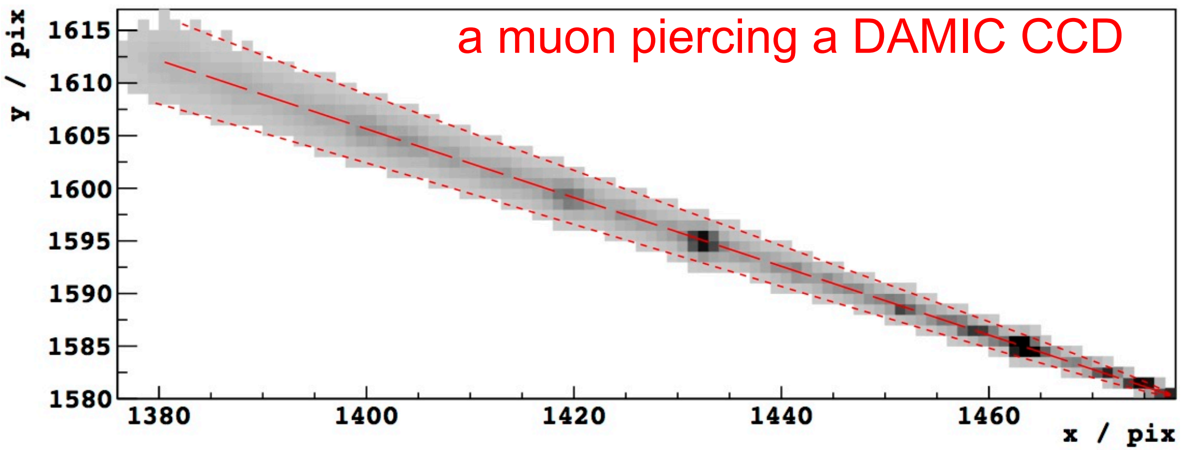
- A readout noise of ≈ 2 e- is achieved by slow CCD readout (≈ 10 min / 16 Mpixel image).

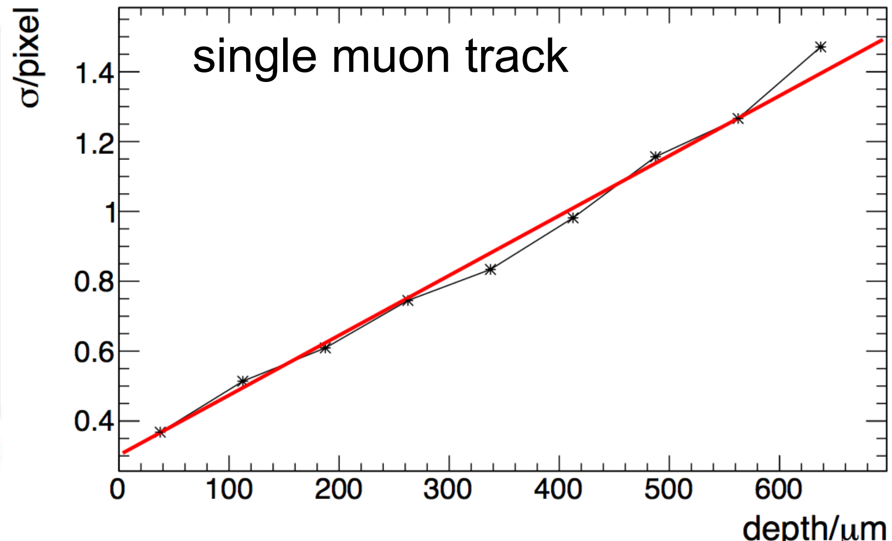
3.8 eV / e-hole pair

1.2 eV band gap

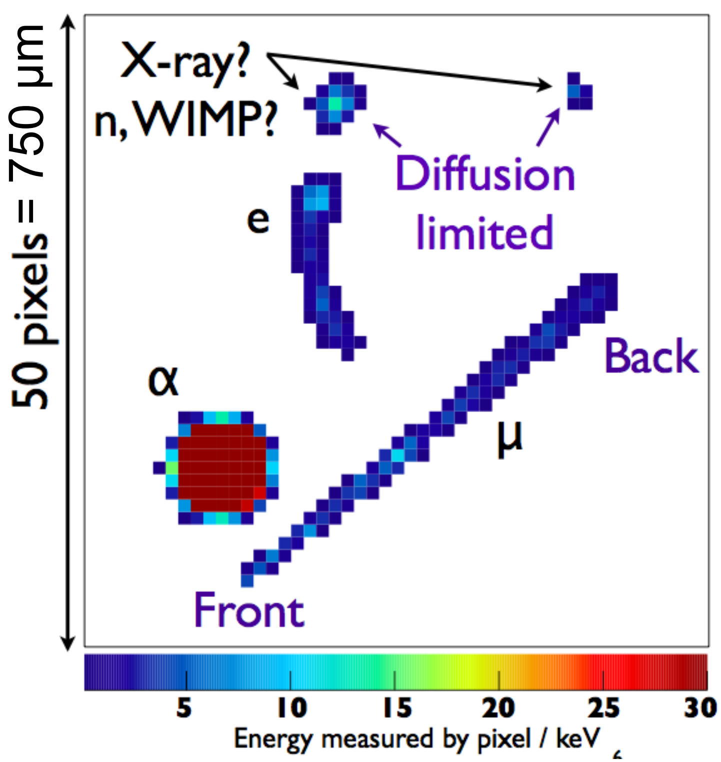
- Very long exposures (8 hours!) to minimize the n. of noise pixels above the energy threshold

3) Unique spatial resolution: 3D position reconstruction and particle ID





$\sigma_{xy} \approx Z$: fiducial volume definition and surface event rejection

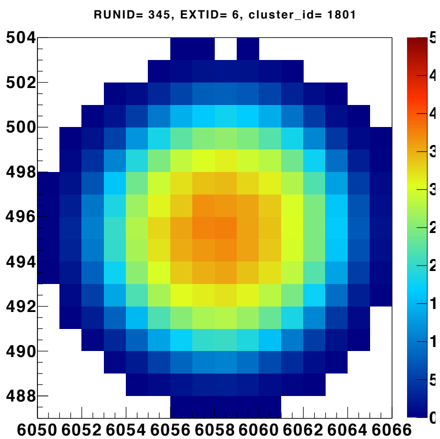


- "Worms": straggling electrons
- Straight tracks: minimum ionizing particles
- MeV charge blobs: alphas
- Diffusion-limited clusters: low-energy X-rays, nuclear recoils

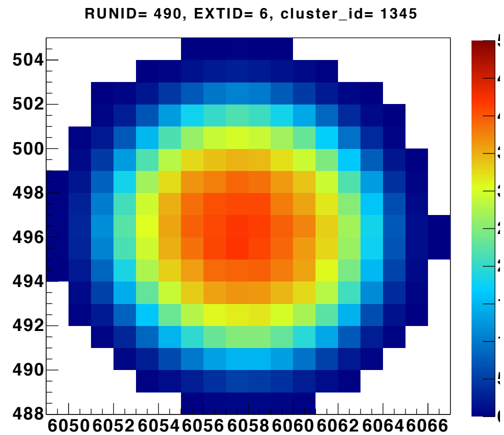
- CCD spatial resolution provides a unique handle to the understanding of the background

Radiogenic backgrounds

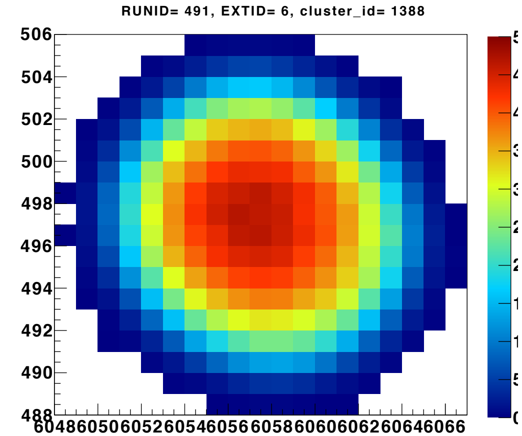
E = 5.4 MeV



E = 6.8 MeV



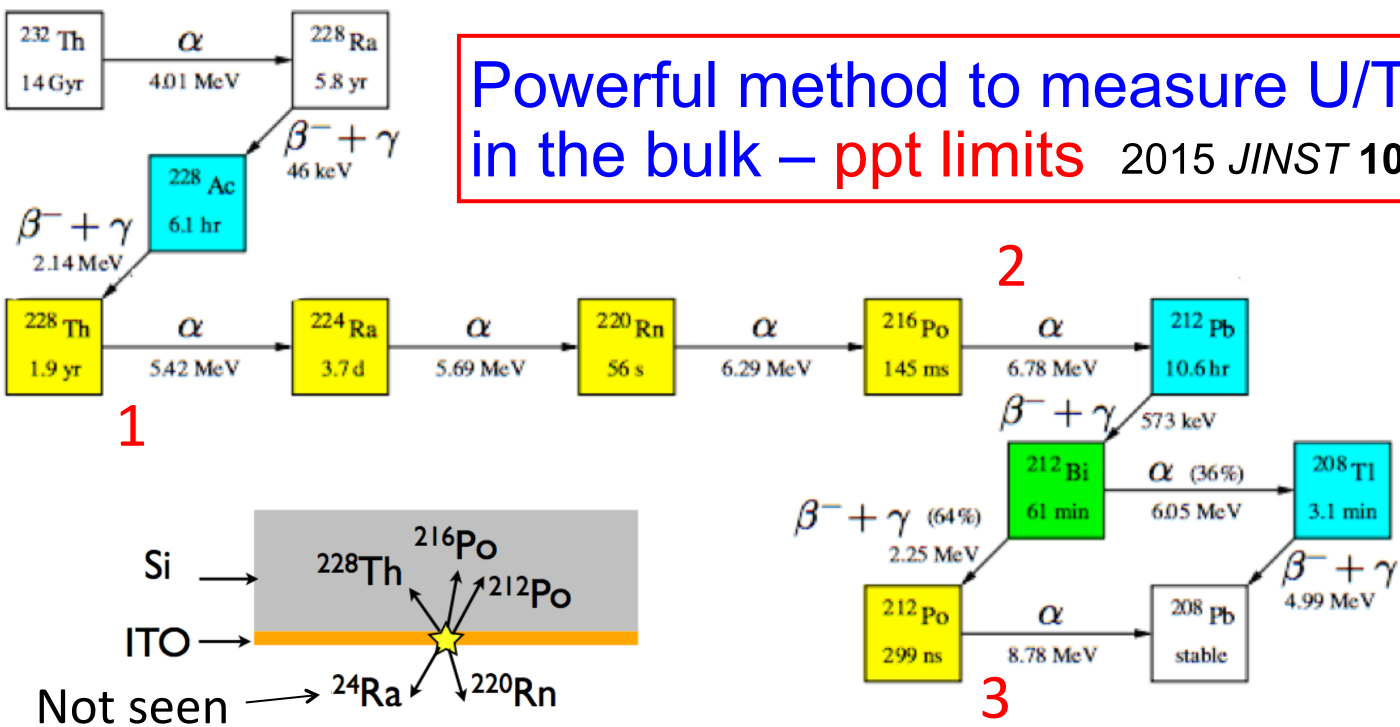
E = 8.8 MeV



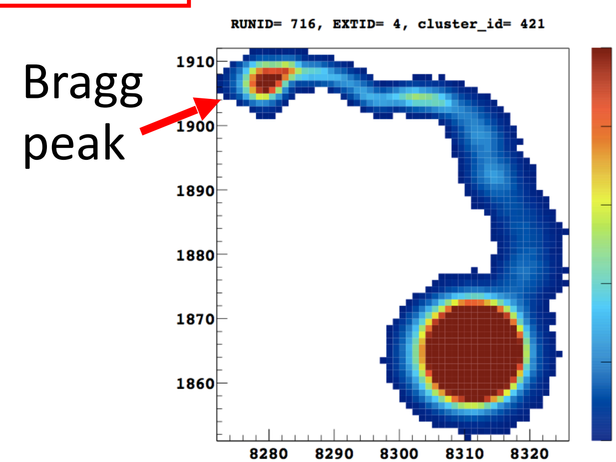
1 Δt = 17.8 d 2 Δt = 5.5 h 3

three α at the same location!

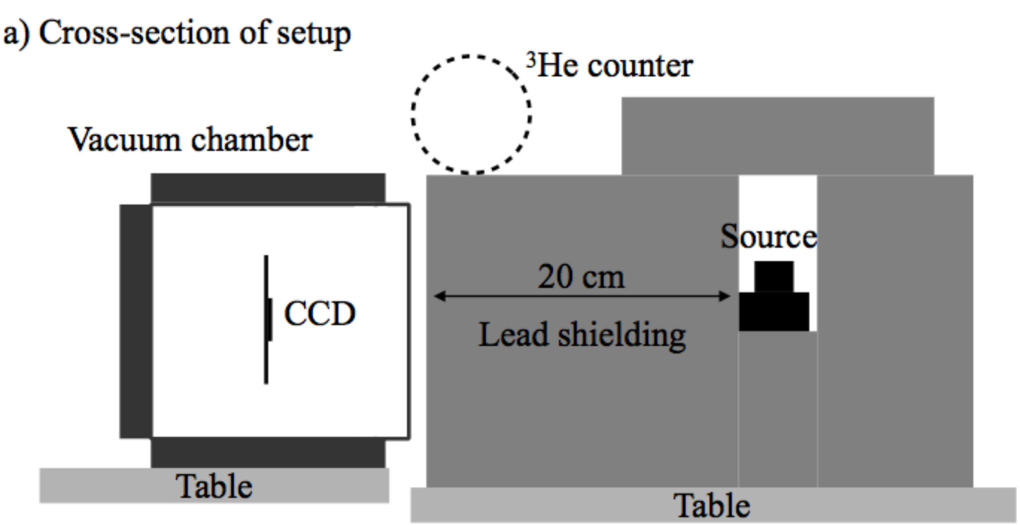
Powerful method to measure U/Th bkg in the bulk – ppt limits 2015 *JINST* **10** P08014

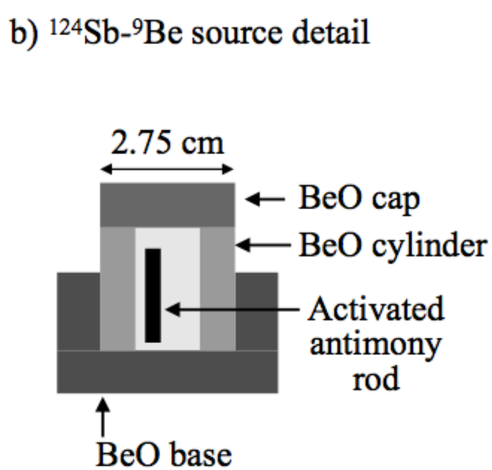


Example of α + β

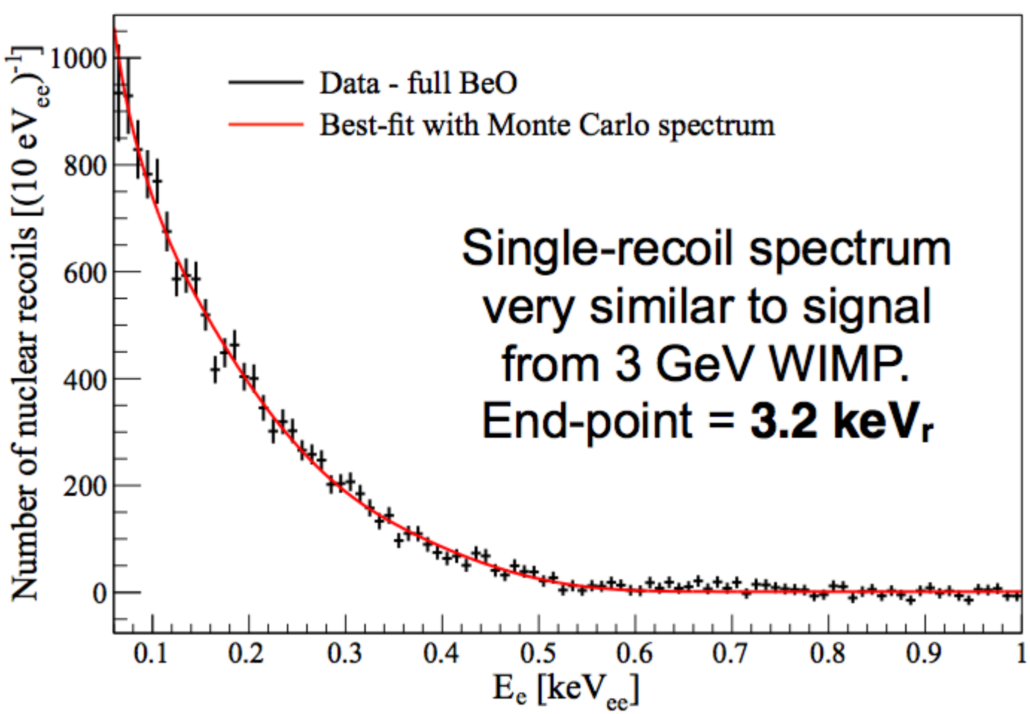


Nuclear recoil calibration

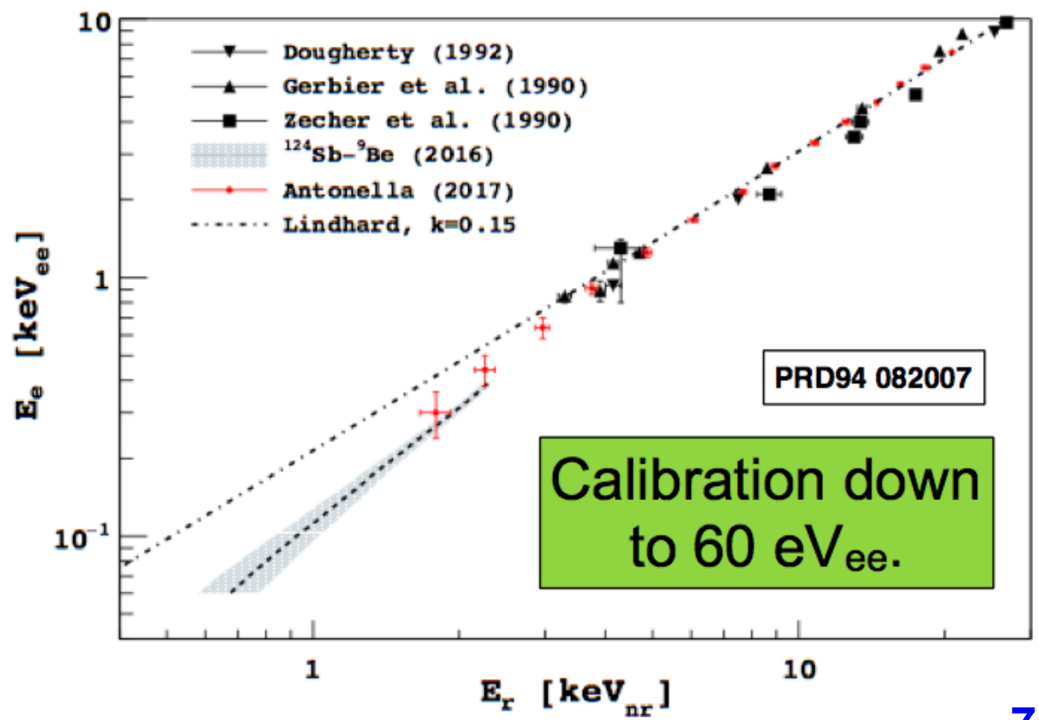




24 keV neutrons from ^{9}Be(γ,n) reaction



Single-recoil spectrum very similar to signal from 3 GeV WIMP. End-point = **3.2 keV$_r$**

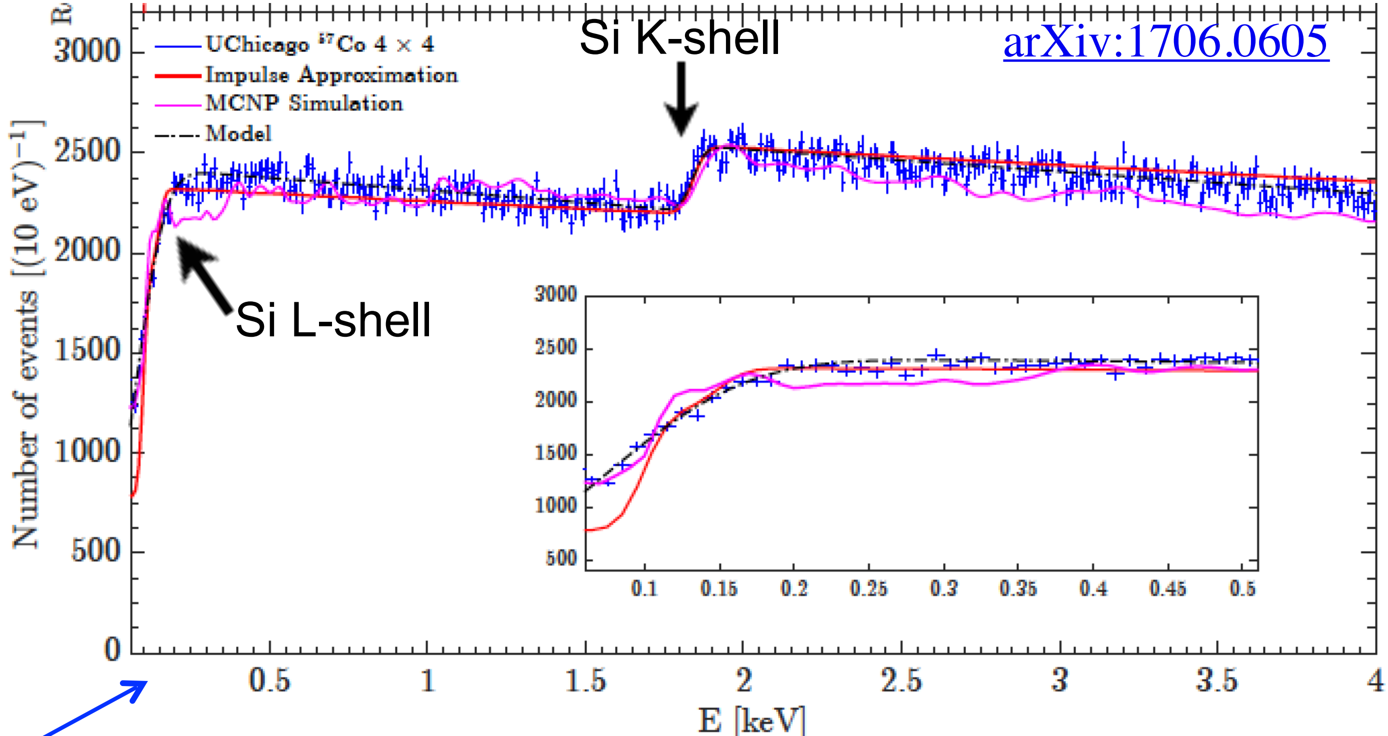


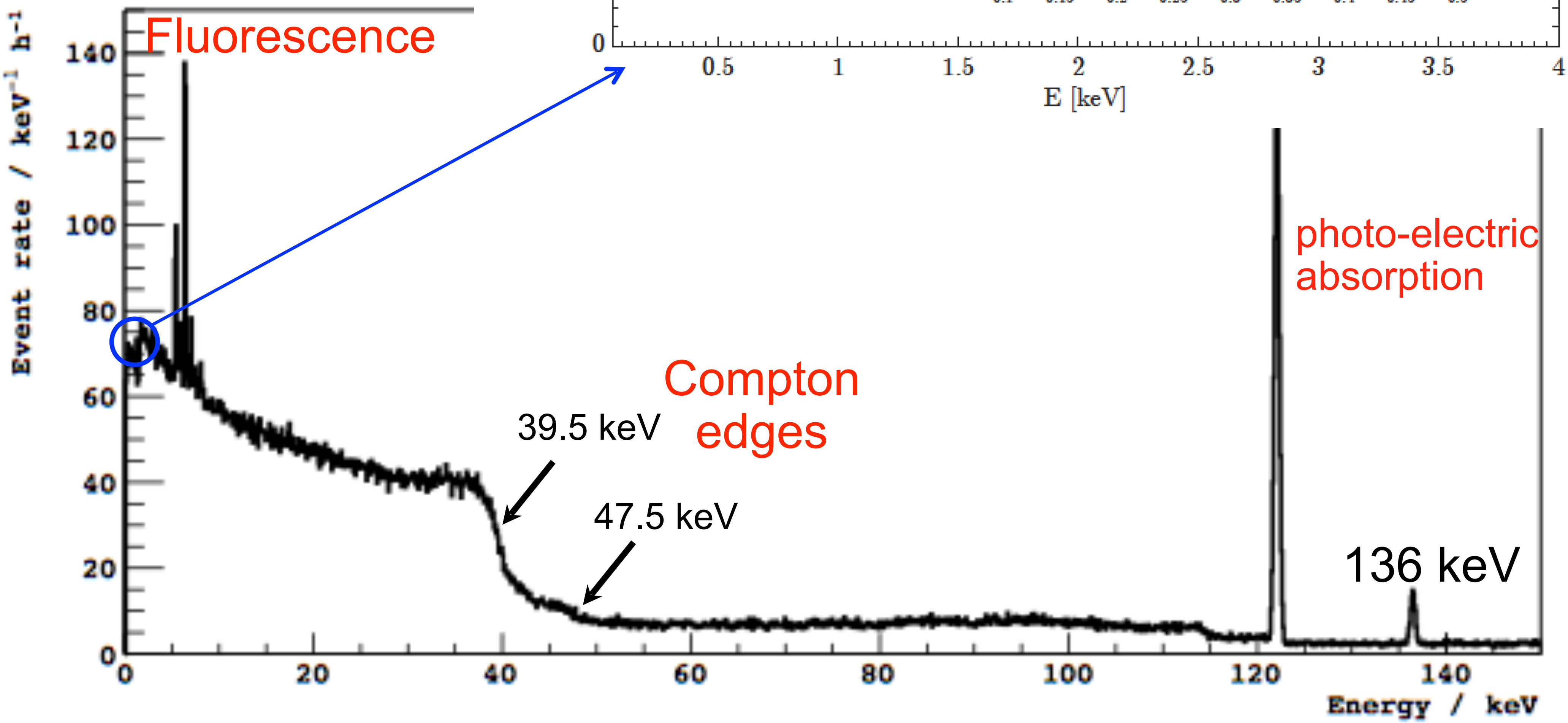
Calibration down to 60 eV$_{ee}$.

Gamma-rays

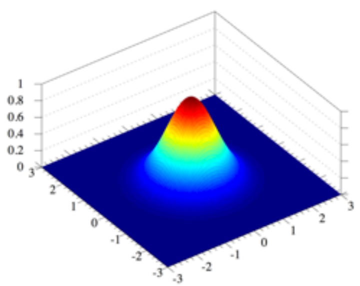
Single-scatter
Compton spectrum

^{57}Co source



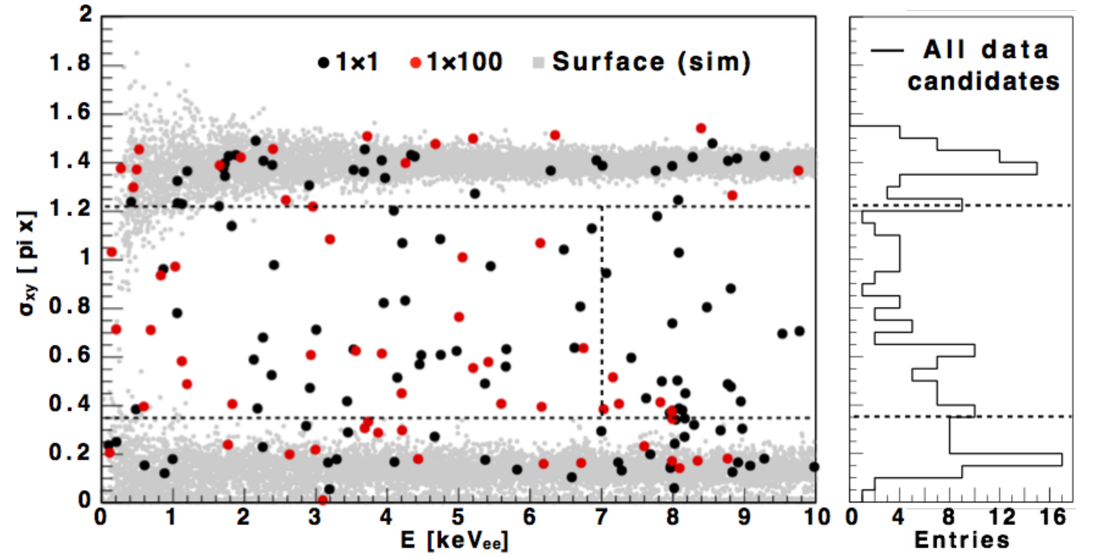


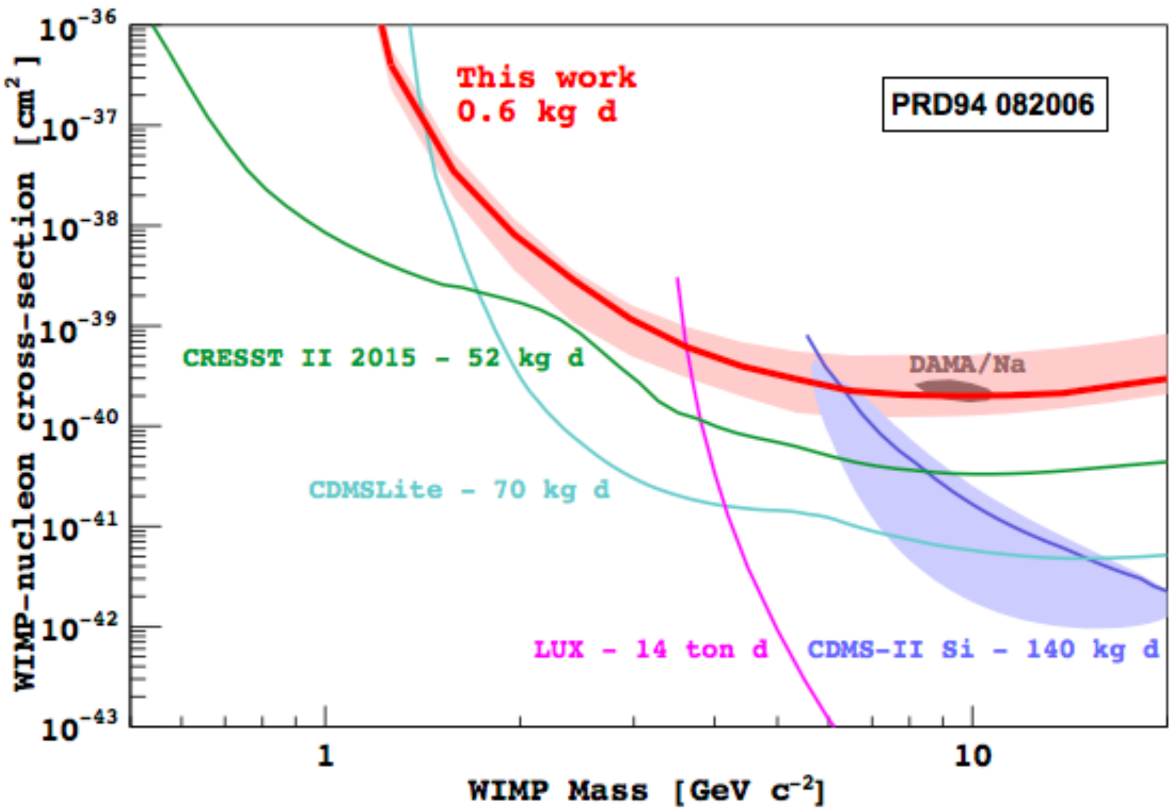
WIMPs search



Measure **E** and $\boldsymbol{\sigma_{xy}}$ for every cluster event.

$\boldsymbol{\sigma_{xy}}$ ≈ proportional to depth of interaction in the bulk silicon





limited exposure taken during R&D phase (bkg. ≈ 30 dru)

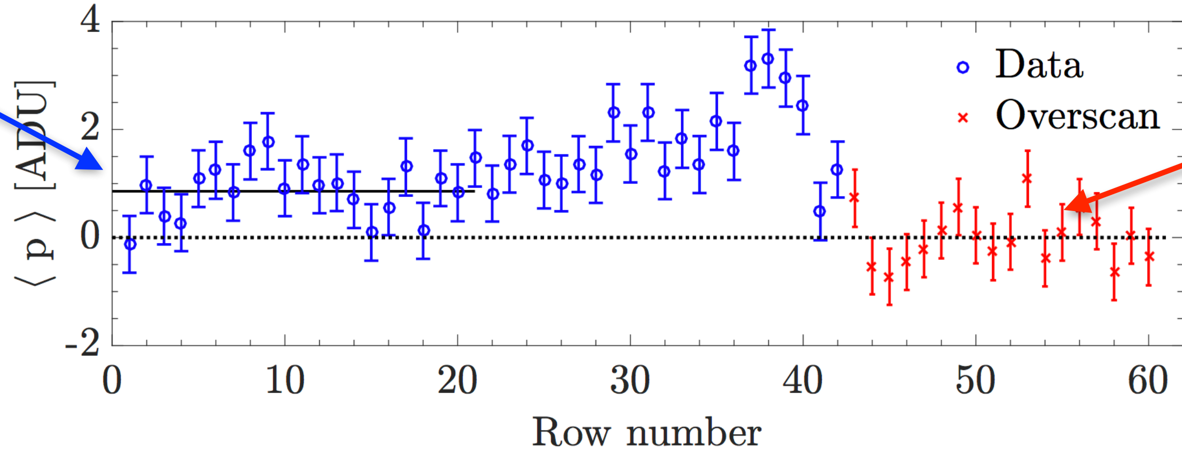
demonstration of DAMIC sensitivity to low-mass Dark Matter

NOTE: current bkg. ≈ 5 dru

Hidden photon DM search

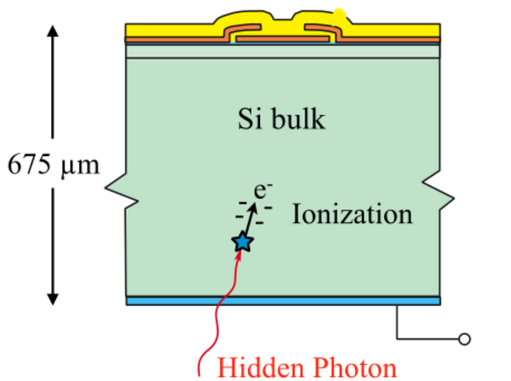
readout noise + leakage current + Hidden Photon

NOTE: 1x100 binning

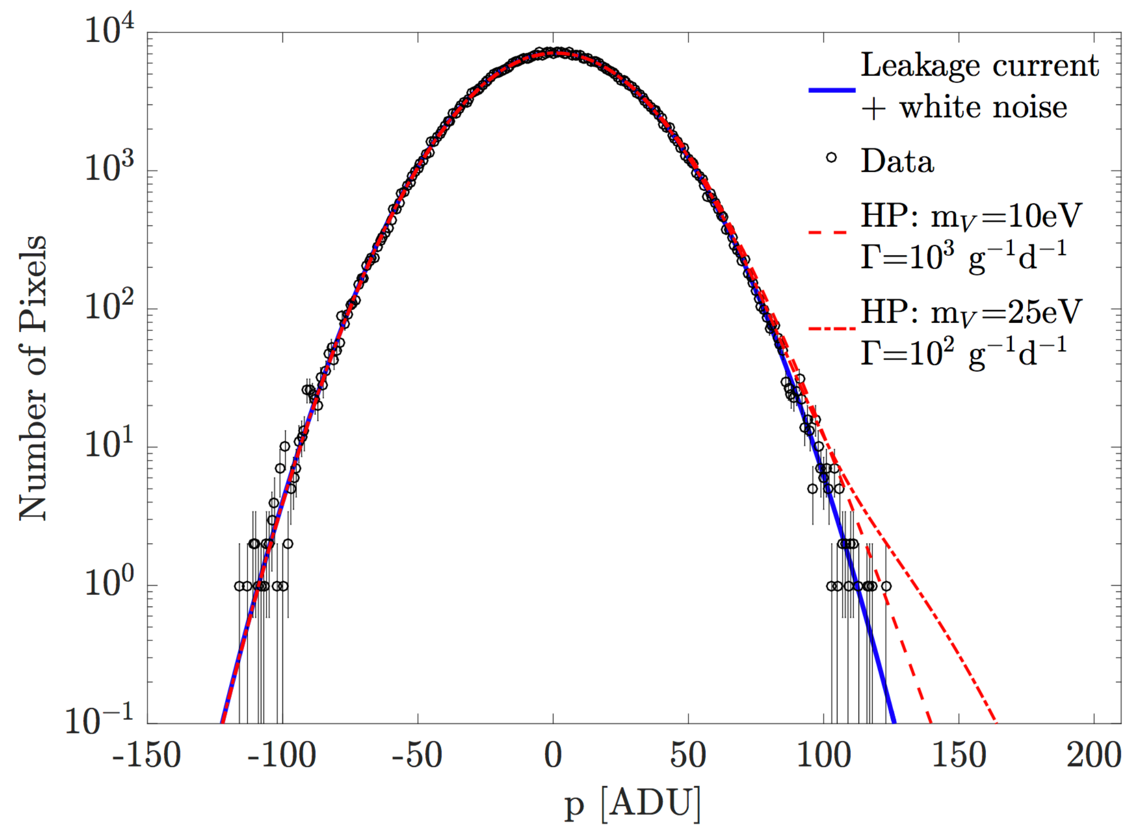


only readout noise in the overscan rows

Absorption of hidden-photon dark matter.



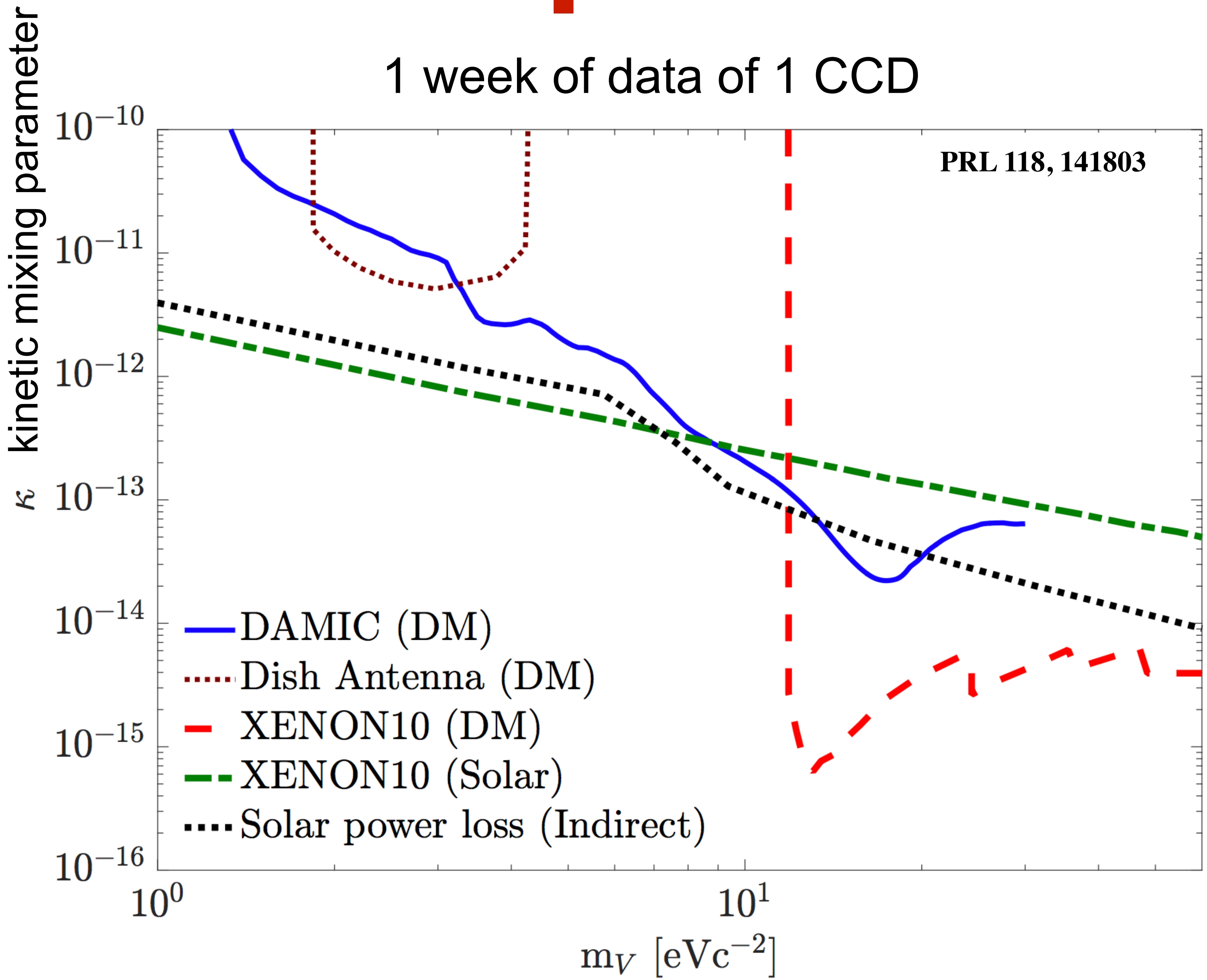
m_V



hidden photon absorption would produce m_V / 3.6 eV charge carriers in silicon:
HP sensitivity in the charge distribution

Hidden photon limit

1 week of data of 1 CCD



Lowest leakage current ever achieved in a Si detector 10^{-21} A/cm^{2} !

DAMIC now

- Already achieved low radioactive background (**5 dru**) and low-noise (**<10 e-**) threshold for a larger detector.

- Stack of 16 Mpix CCDs: DAMIC100 in current SNOLAB vacuum vessel and shielding.

- Installation took place in January, results with ≈ 10 kg day of data expected in 2017/2018.

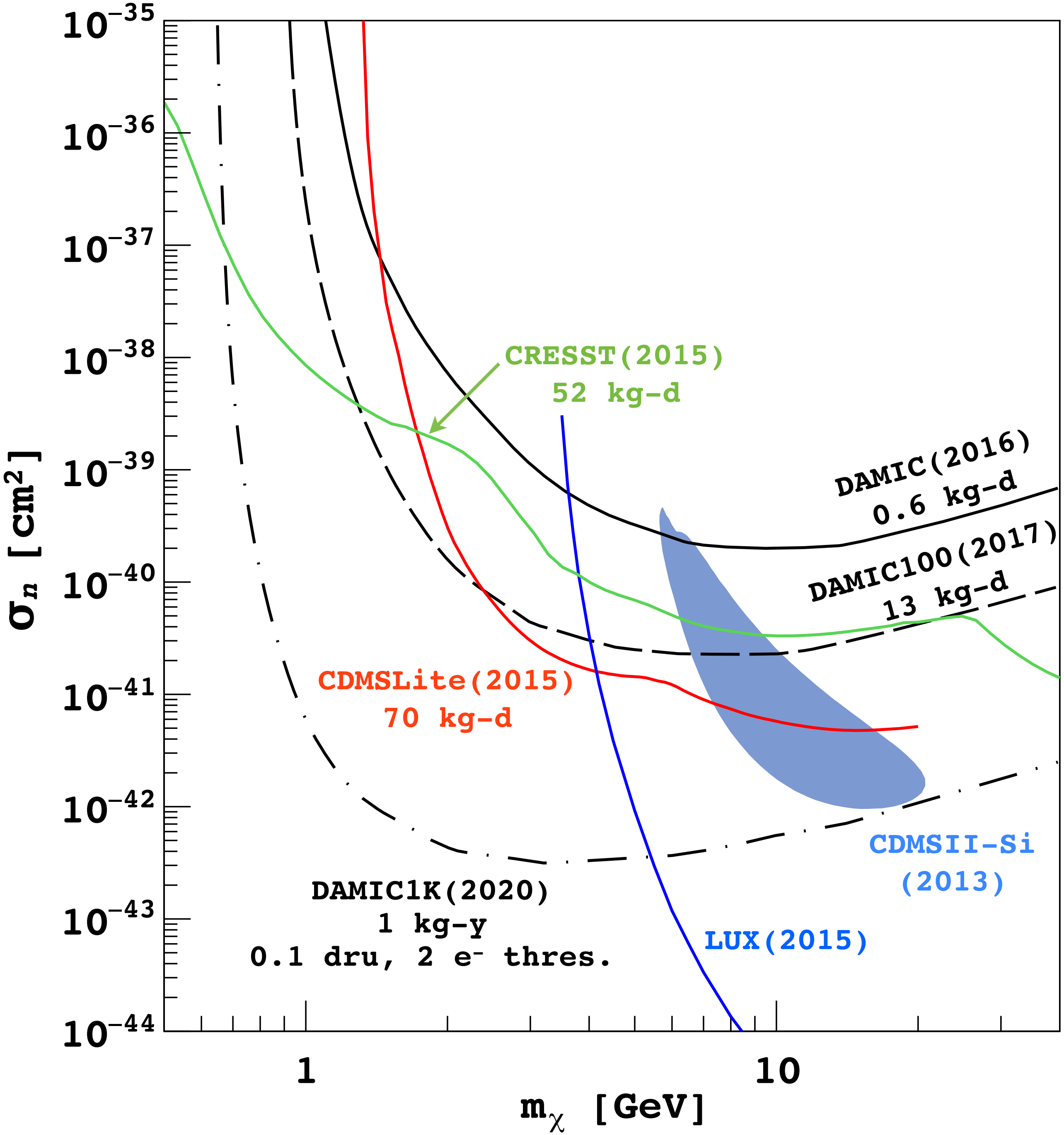
- Ongoing R&D for thicker, larger-area CCDs for a lower-noise, lower-background kg-size detector.

DAMIC-1K

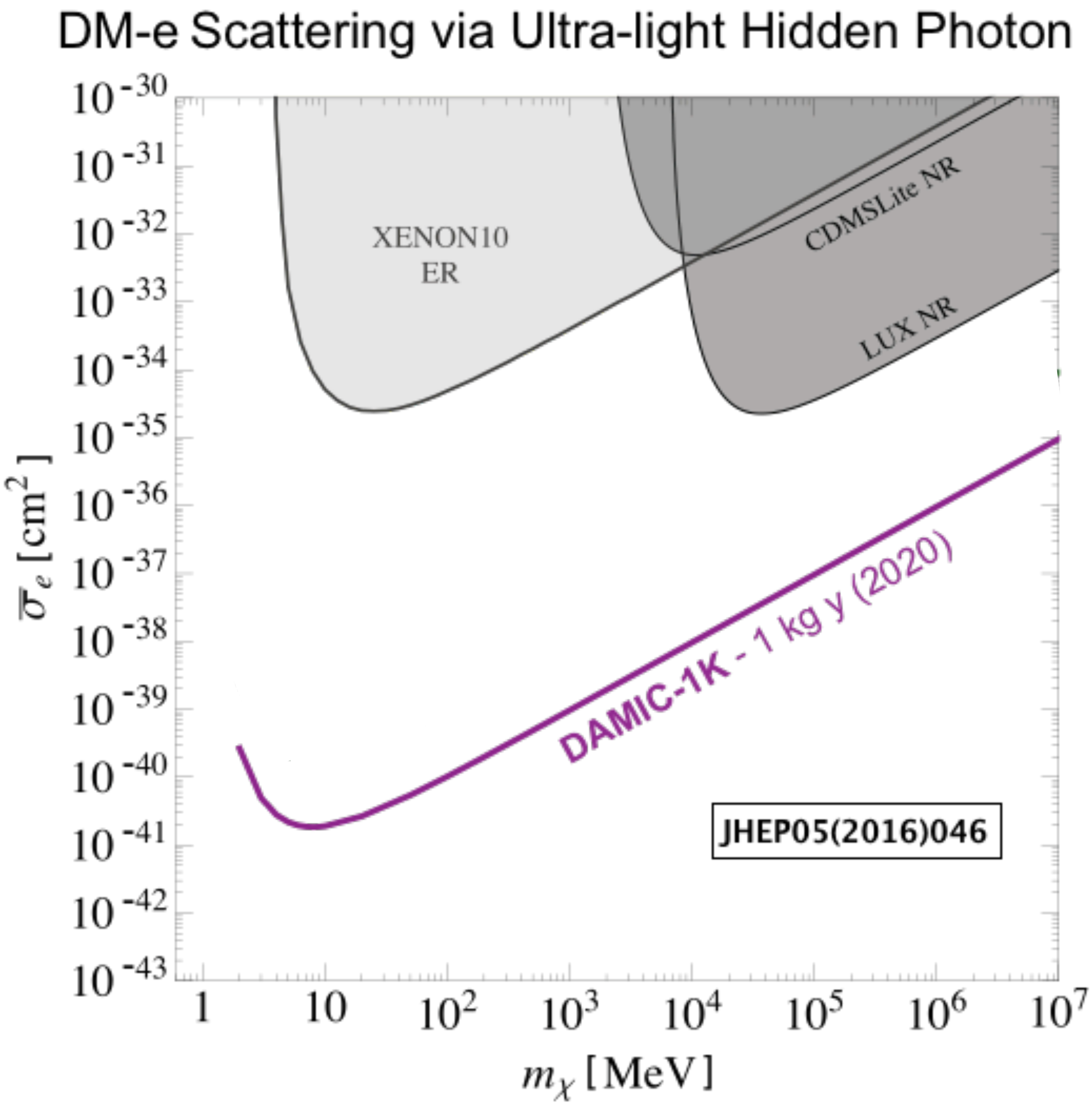
- A kg-size experiment with **0.1 dru** background and **≤ 2e-** threshold

- To lead the exploration of WIMPs and dark sector candidates in the low-mass DM parameter space

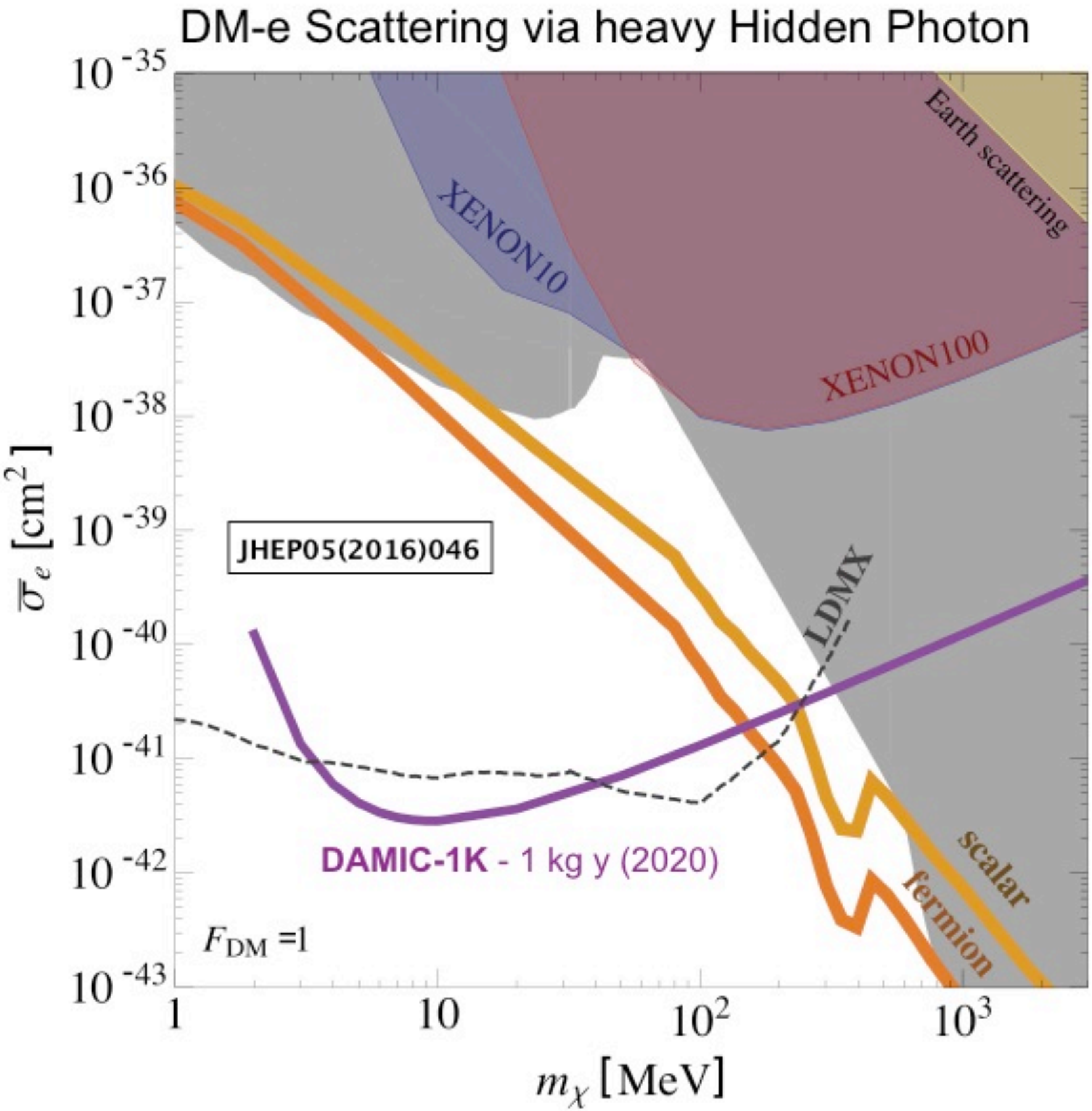
DAMIC-1K and WIMPs

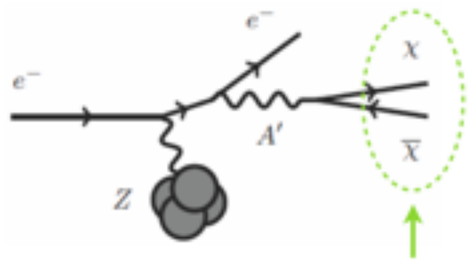


DAMIC-1K and dark sector



DAMIC-1K and dark sector



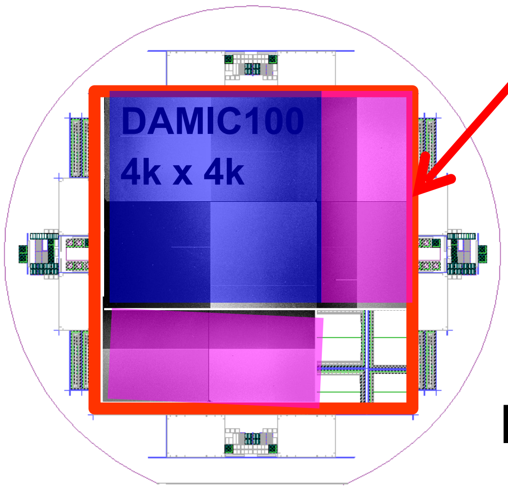


Complementary to accelerator searches!

DAMIC-1K technical challenges

- A kg-size DAMIC can be built <u>with the existing technology</u>

Silicon wafer



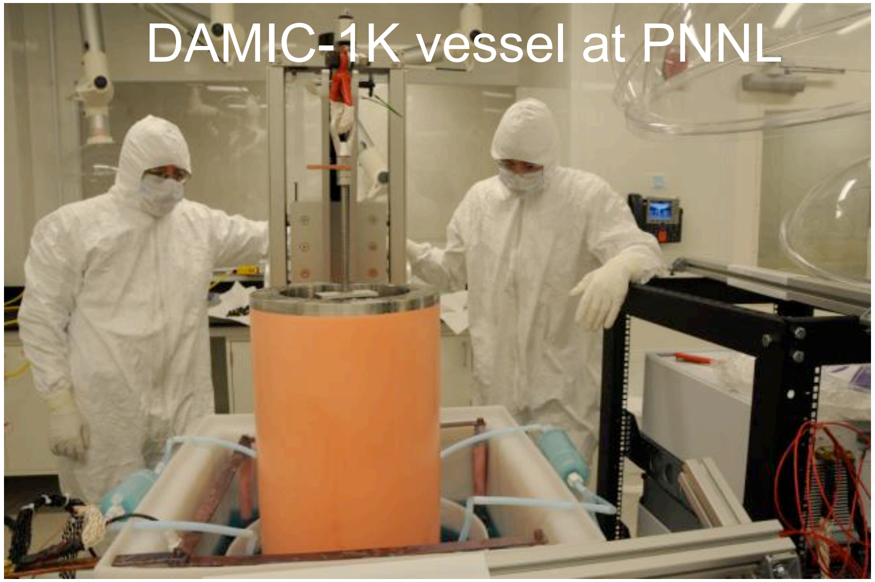
6k x 6k pixels, 1 mm thick

≈ 20 g / CCD

≈ 50 CCDs / 1 Kg

DALSA has confirmed the feasibility to fabricate these larger and thicker CCDs

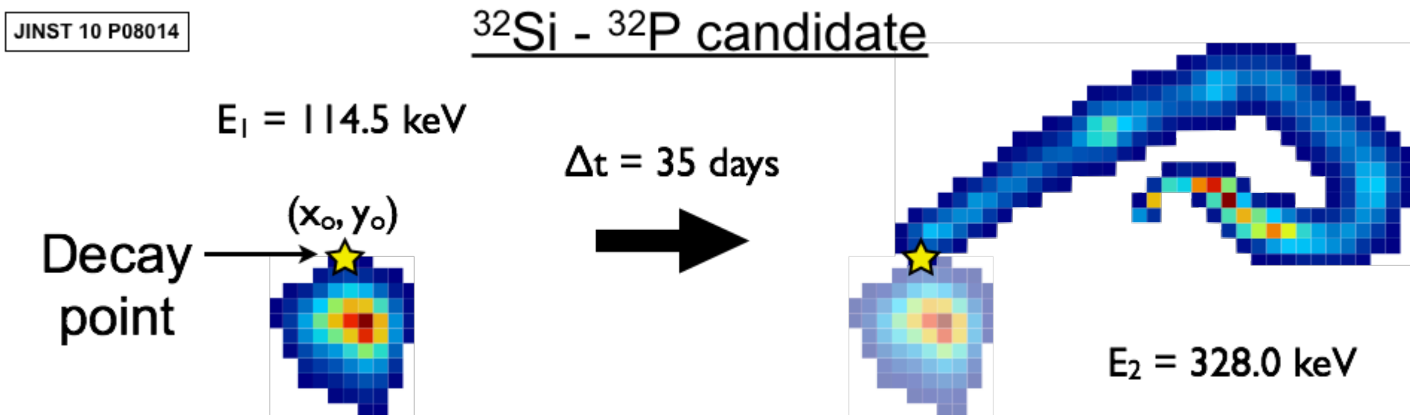
R&D for > 1mm-thick CCDs started at UChicago Pritzker Nanofab



- Background
  from a few dru to a fraction of dru.
  external bkg.: improved design, materials (e.g. electroformed copper), strict procedures (silicon storage underground, radon, surface contamination)
  internal bkg.: cosmogenic ^{32}Si and tritium

DAMIC-1K background

- Cosmogenic ^{32}Si rate will be accurately measured by the current detector at SNOLAB



≈ 1 dru (dominant bkg. in SuperCDMS); rejected in DAMIC-1K by spatial correlations

- Tritium expected to be the dominant bkg. for DAMIC-1K.

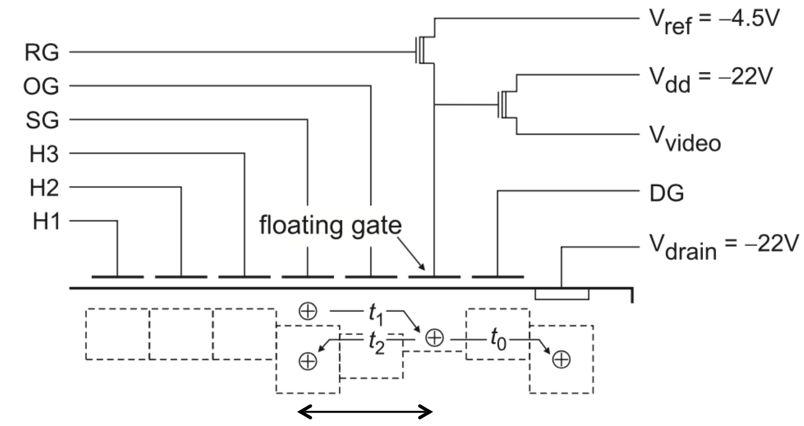
<u>A measurement of its rate may be within reach of the current DAMIC detector at SNOLAB</u> (so far only estimates are used for forecasts)

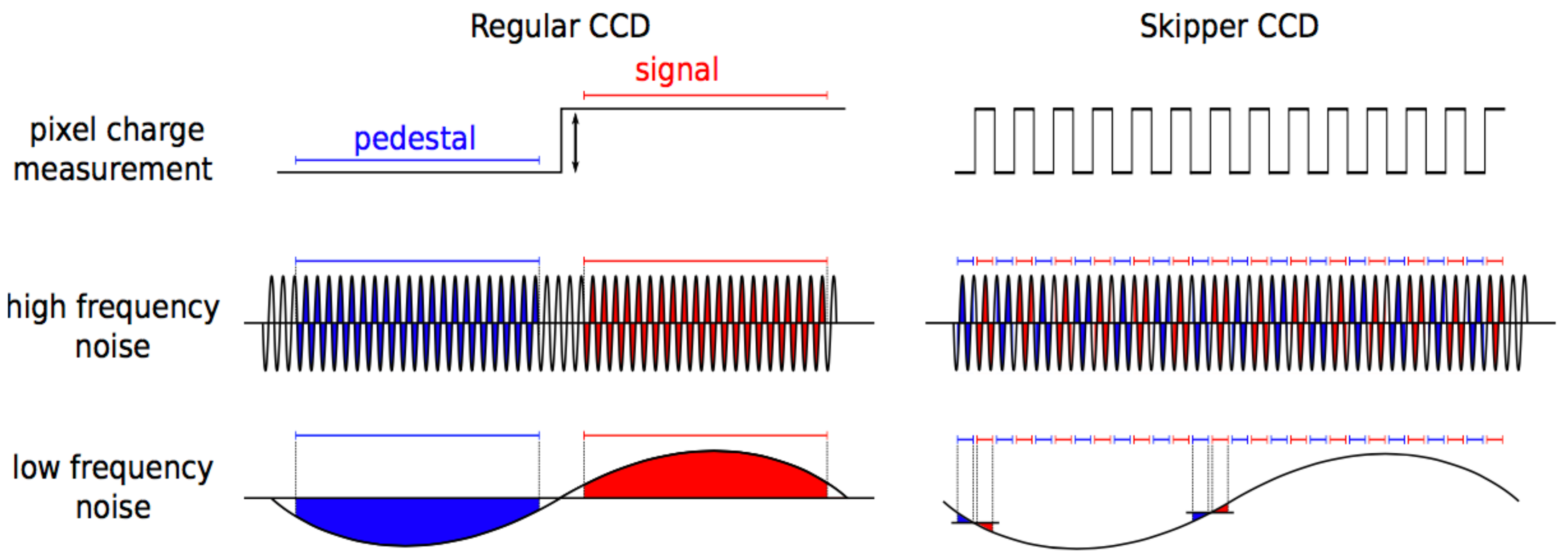
DAMIC-1K sub-e⁻ noise

- Skipper readout

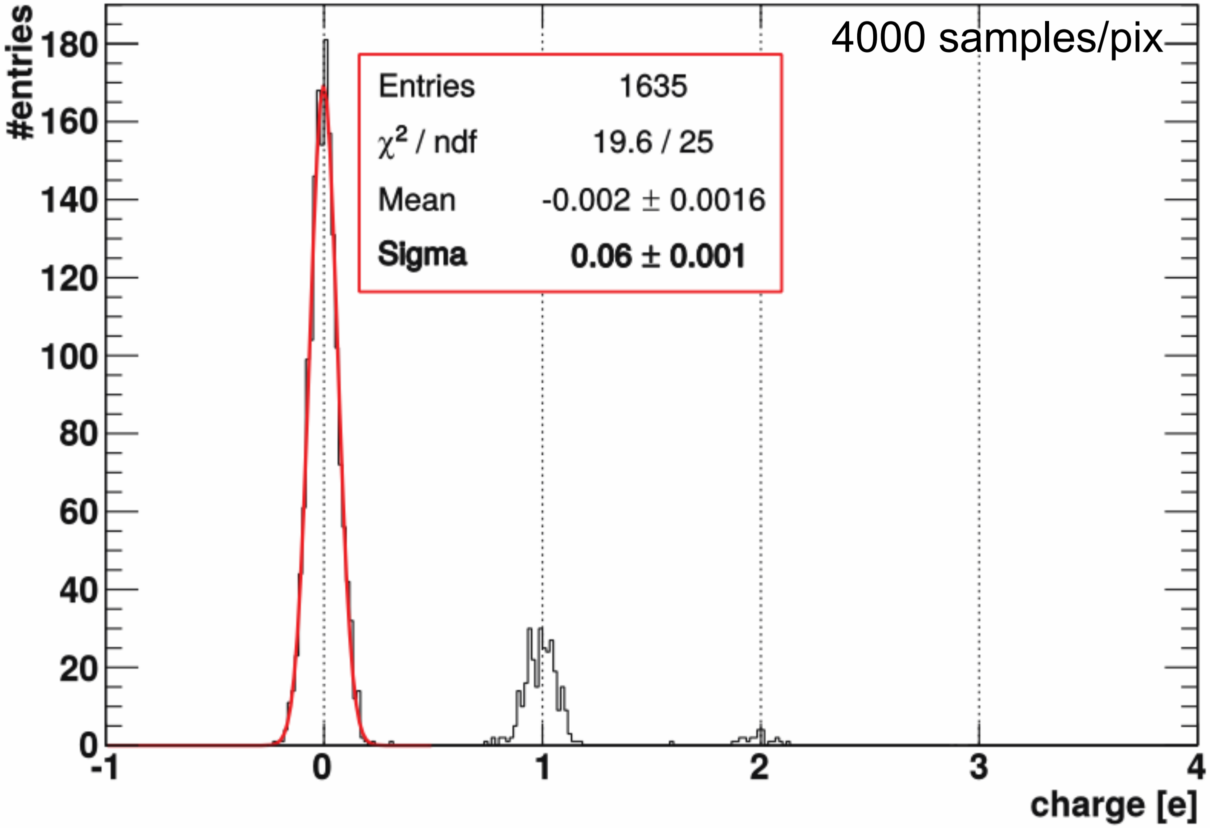
Non-destructive measurement of the charge!

Measure the charge fast (kill 1/f noise) and N times (noise ≈ 1/√N)



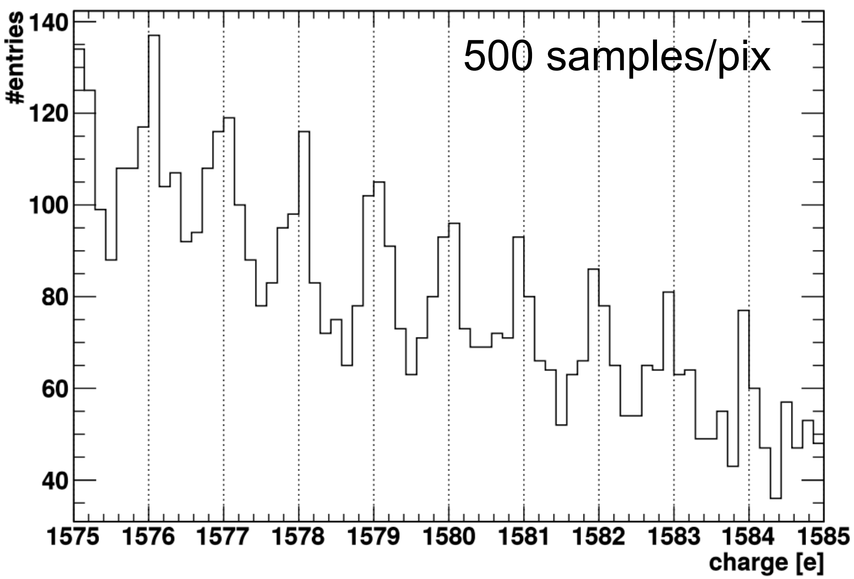


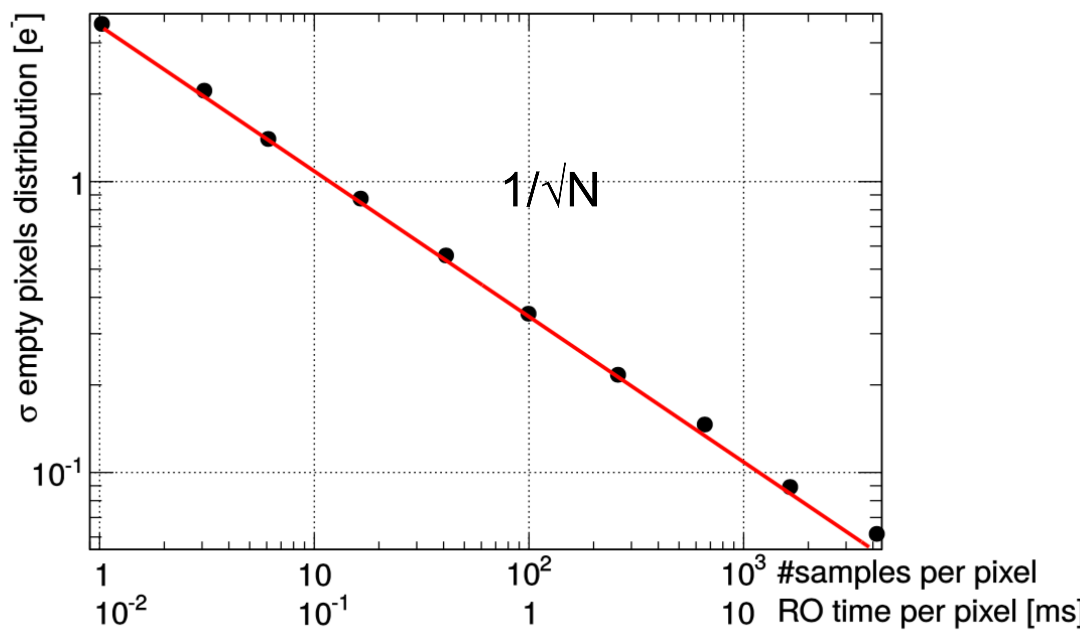
DAMIC-1K sub-e$^-$ noise



Skipper unprecedented sensitivity demonstrated on a small size DAMIC CCD (J. Tiffenberg, SENSEI LDRD Fermilab)

single electron resolution AND low leakage current essential for DM-electron





DAMIC-1K requirements

- We will need to increase significantly (with respect to DAMIC100) the infrastructure, support and activity underground in order to meet the demanding low-background goal of this next stage of the experiment. In particular:

  Packaging and test of the CCDs to be performed underground in a radon-free clean room to minimize activation (tritium) and surface backgrounds.

  Detector assembly to be performed in class 100 clean room in radon-free air.

  Requires adequate infrastructure and a larger footprint

  For DAMIC-1K to continue at SNOLAB, stronger lab support is required (DAMIC is the only SNOLAB experiment with no collaborator from Canadian Universities)

Conclusions

- In the last three years DAMIC has established the CCD technology as a competitive technique for the search of low-mass Dark Matter particles. Unique amongst dark matter experiments for its spatial resolution and single-electron resolution and extremely low leakage current
- DAMIC100 currently taking data at SNOLAB. Main results expected: precise measurements of backgrounds (^{32}Si and tritium) and DM limits with O(10kg day) exposure
- Preparing for DAMIC-1K, a kg-size CCD detector with low background and sub-electron noise, which will explore a new large parameter space, scrutinizing the WIMPs paradigm, as well as dark sector candidates with sensitivity comparable to accelerator searches
- The DAMIC-1K detector is an incremental step of proven technologies (larger size CCD, sub-electron noise). It will work as specified.
- DAMIC-1K will require a significantly larger support than DAMIC100 from the hosting lab